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The great difference between man and the other mammals is that man can learn to speak and to understand the meaning of speech. It is by means of the spoken and the written word that the ignorance of childhood is changed into the understanding thought of educated men and women.

Bees have a language, as Karl von Frisch has described so entertainingly. Dogs, monkeys, birds communicate with their own kind. But they use a language which is largely inherited, inborn.

Man has a spoken language which must be taught to each growing child. His ability to learn to speak depends upon the postnatal organization of speech mechanisms within his brain. When a baby comes into the world the speech areas of the cerebral cortex are like a clean slate, ready to be written upon. Other forms of movement and sensation, on the other hand, depend on inborn mechanisms which resemble those of other mammals.

When the gross structure of the human brain is compared with that of animals, no new speech organ is evident. The brain of the dog resembles ours in general organization, and that of the chimpanzee still more so. All the lobes which form its major subdivisions are present. The pathways of muscular control are like ours. They have large areas of cerebral cortex devoted to seeing and hearing and feeling and even larger areas for smelling.

Animals learn from experience, as we do, and they remember what they have learned. More than that, they seem to have unique

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racial memories which guide them in their behaviour, especially at crucial times in their lives. This memory, which we call instinctive, is strangely lacking in us.

If we did not teach, and if we could not learn, we would be more helpless than all other mammals. In the observations which follow it is my purpose to question the accepted methods of teaching foreign language. I venture to do this, not because I claim any specialized knowledge of pedagogy, but from the point of view of familiarity with the cerebral speech mechanisms and their derangements.

Speaking, and the understanding of speech, also reading and writing depend upon the employment of certain specialized areas of the cerebrum. There is an optimum age when these special areas are plastic and receptive, and my purpose in this rambling, pseudo-scientific discussion is merely to remind educators of this fact.

In the history of our race, we know little of the beginnings of speech. It has been said that it was when man learned to cultivate grain in the valleys of the Nile and the Euphrates that the birth of civilization was made possible. But there was a more important prerequisite to that civilization – the learning of a language. The writing of that language came later, and its evolution can be traced in the tablets of Mesopotamia.

I remember a day when I stepped out of the blazing sun of a street in Baghdad into the Iraq Museum. There, in the museum's half light, I saw rows of clay tablets, each of them shaped like a piece of soap. On them could be seen the stages in the story of writing from picture-drawing and counting to alphabet.

Seton Lloyd, then Curator of the Museum, picked up a tablet and held it in the palm of his hand just as some Sumerian scribe must have held it when it was soft clay more than 5000 years ago. He pointed out the pictograph of a bag of barley and the single mark of the stylus which stood for the number ten (the number of a man's fingers) and the different marks which were used to represent ones. Here was a record of sale at a time when men had learned to cultivate grain in that fertile plain, a time when speech was probably quite well developed and when man was about to turn from pictograph to writing, an evolution which seems to have been relatively rapid.

Today we have learned to understand something of the cerebral mechanisms which enabled man to begin to speak, and later to write and read. I shall describe these in simple outline.

The two cerebral hemispheres of man are homologous. They are mirror images of each other. The cerebral cortex, which covers each hemisphere, is identical in cellular structure when the two sides are compared.

Animals employ each hemisphere for movement and sensation on the opposite side of the body, as we do. Nerve impulses which utilize these twin hemispheres come from central or centrencephalic gray matter in the brain stem that joins the two. But the function of each is like that of the other.

When a child begins to speak, there develops a functional specialization in one cerebral hemisphere, normally the left hemisphere where the right hand is also represented. There are separate areas of the cortex on this, the dominant, side which come to be devoted to the formulation and the understanding of speech. Meanwhile the slate continues to be blank on the right side. Curiously enough, the areas of the right hemisphere, which are homologous to those used for speech on the left, seem to serve no discoverable purpose, while those areas remain intact on the left side.

The cortical representations of speech are indicated by stippled areas in Figure 1. We have been able gradually to work out their more exact position during a succession of operations under local anaesthesia when cortical excision was being considered in the treatment of focal epileptic attacks. We have learned that, if these areas are avoided, removal of seizure-producing cortex will not result in speech paralysis or aphasia.

The areas have been identified by using a gentle electrical current to produce local interference in the cortex while the patient is talking and naming objects shown to him by one of my associates.*

By the electrical interference method in conscious patients, it

*At the present time, Dr. Lamar Roberts and the writer are analyzing about 575 such cases in a study to appear shortly. We have had the help of Mr. R. W. Sparks, speech therapist. An earlier study of such cases was made by Dr. Preston Robb, and those in which the frontal lobe was involved were published (1948). Penfield and Rasmussen have recorded evidence regarding vocalization and arrest of speech (1949; also 1950).

is possible to recognize in the dominant hemisphere three essential areas of cortex devoted to what might be called the ideational aspects of speech, and one such supplementary area (Fig. 1). The frontal speech area is quite separate from the parietal and temporal speech areas. It is possible that the latter two may be continuous. It has not been feasible to explore the depths of the intervening fissures to decide this point. The posterior limits of these two areas also cannot be sharply drawn, but the anterior frontiers can.

Injury to any one of these three areas produces a defect in the ideational mechanisms of speech, or aphasia. Removal of the cortex between the frontal and parietal speech areas does not produce aphasia, although it does produce awkwardness of speaking for reasons that will be apparent presently.

Curiously enough, as Dr. Roberts has pointed out, interference with one cortical speech area produces aphasia which differs little in pattern from that produced by injury of any of the others. Even the supplementary speech area, which may be removed with no more than transient aphasia, produces, when an electric current is applied to it, a disturbance of the ideational mechanisms of speech which resembles that produced by electrical interference with the others.

One must conclude, then, that the organization and coordination of the speech mechanism are carried out by neurone connections that are subcortical but within the same hemisphere.

The ideational speech mechanism is within the dominant hemisphere. It is somewhat like the movement of a watch in the following respect. Interference with one of its cortical parts causes it to stop or to slow down, although each cortical part may well play a very different role in the perfect functioning of this mechanism.

But there is more to speaking than the ideational process involved. There is articulation produced by control of mouth, lips and tongue, and there is vocalization produced by control of the larynx and the muscles of respiration, including the diaphragm. There are four areas of the cortex from which vocalization can be produced by stimulation of the human cortex, the lower precentral, or pre-Rolandic, gyrus of each hemisphere and the supplementary motor area on each side. This is shown in Figure 1 for the left hemisphere, but the right would be the same in this regard.

It seems likely that each of these cortical areas is able to activate by its connections a common mechanism in the brain-stem, for, from each area, the patient is caused to make a similar involuntary cry, a long-drawn-out vowel sound.

Stimulation of the cortex of the chimpanzee, the dog, or the cat does not produce vocalization, although these animals are able to vocalize each in its own way from the day of birth. One may surmise, then, that in the case of man there is establishment of four additional representations of vocalization in the cerebral cortex, and that each of these four areas preserves an activating connection with the vocalization center in the brain-stem. One may assume also that the appearance of this representation in the cortex is closely related to man's ability to speak.

The new-born kitten or the new-born puppy raises its voice to announce the pangs of hunger, that seem to usher it into the world, just as effectively as the new-born baby does. But, at a later period, when the cerebral cortex begins to function, only the child is ready to learn to speak.

Articulation of words calls for control of movement of the mouth, tongue and throat. These movements have their cortical representation in the lower precentral gyrus of each hemisphere, in the same general area as vocalization. But this cortical representation is found in the other mammals as well as man, no doubt because of the fact that these are the same structures that must be controlled in eating, a function in which man can claim little superiority over his fellow mammals.

Thus, it is clear that the cerebral cortex of man contains within the framework of its voluntary motor system on each side a considerable representation of the movements of articulation and vocalization. This is its inborn organization. It is the motor mechanism for speech, and one hemisphere is as well endowed as the other for this purpose.

But in the learning of speech, which begins at the close of the first year of life, the newly forming ideational mechanism makes its appearance in one hemisphere, not in both. In the elaboration of this function there seems to be a need for a new form of specialization.

It is interesting to observe the positions which the areas devoted to speech come to occupy. The frontal and parietal speech areas

(Fig. 1) are placed on either side of the voluntary sensorimotor strip, quite close to the representation of articulation and vocalization. The supplementary speech area is adjacent to the supplementary area for vocalization. The temporal speech area is placed between the visual cortex and the auditory cortex. This portion of the temporal lobe takes part in essential mechanisms of memory.

Reading and writing seem to depend particularly on the integrity of the cortex between the temporal speech area and the visual area, for injury in this zone results in more severe interference with these functions than with the use and understanding of the spoken word.

Thus, it is apparent that, at birth, mechanisms for movement and sensation are pre-formed. The infant vocalizes and uses its mouth and tongue with great vigor and effectiveness. But the areas which are destined to be utilized for the ideational mechanisms of language and reading and writing are unorganized, waiting for the dawn of understanding.

In the beginning, the child's brain seems to be functionally plastic as far as the location of the speech mechanisms is concerned. If an infant, who has begun to speak, suffers a large injury to the left hemisphere, he may become dumb for as long as a year. Then he learns again by utilization of homologous areas in the cortex of the right hemisphere. An older child might do this but with increasing difficulty.

On the contrary, however, the adult who receives such a widespread injury to the left hemisphere may never succeed in making the transfer, may never speak and read and write again with any degree of perfection. Speech therapy and effort will help repair the defect in inverse ratio to the extent of the lesion. Capacity of substitution of one hemisphere for the other is truly amazing during infancy. But, once functional localization of acquired skills has been established, the early plasticity tends to disappear.

Some of these physiological and anatomical facts that I have discussed in brief outline are new. But many of them have been common knowledge since Broca (1861) first declared that speech had a localized representation in the brain.

It is obvious that the little child, learning to speak his mother's tongue, does so without accent and without apparent effort. When

he learns words he is learning about life. Language provides him with a way of asking for, and usually getting, what he wants; a way to share the exciting ideas, that teem in his new-born imagination, with others who love him; a way of understanding the intriguing romance of fairy tale and the equally intriguing mechanisms of steam engines, dump trucks, animals and dolls. For him language is a means to an end and not an end in itself.

At first he mispronounces his words and he creates a delightful "lingo" of baby talk. But all too soon, perhaps, he drops these mispronunciations and adopts the less interesting way of talking used by the adults about him. The mother's method of teaching language is amazingly efficient!

If, before the age of 10 to 14, the child associates with those who speak a second and even a third language, he can learn by a similar technique two or three languages with no evident increase in his effort.

I had the opportunity of watching this experiment carried out in my own home. Two of our children spoke German in the nursery with a German governess from the beginning. Then, when they first went to school it was to a French nursery school at the ages of 3 and 4. There, work and play were presented to them in the French tongue.

In the nursery with the governess it seemed to them quite natural that the word for dog was "hund." In the nursery school it was "chien" and when they were with their parents it was "dog." There was no confusion, no extra effort, no foreign accents. The change in environment was sufficient to change the way of expression. Or the appearance of the governess who never spoke anything but German might have the same result. The parents also spoke German to the best of their ability in the nursery. This established what may be considered a conditioned reflex.

The experiment was successful. Even the two older children who had played with German children for only a few months at the ages of 9 and 10 continued to talk with the German governess who entered the family at that time. In each case fluent command of the language was achieved without labor, and the ability has since served useful purposes to three of the four children.

Compare that with the experience of their parents who learned English at home in the usual way and later, between the ages of

16 and 22, according to accepted school curricula, they studied French and German with Latin and a smattering of Greek thrown in. Still later Spanish was taken up for a special purpose by the excellent Berlitz method. It was all done with textbooks and word lists and rules of grammar and syntax – home work, toil, trouble and headache.

All this was hard work. The time required was great. The discipline was said to be good for the character. But if the object of it all was to speak easily without accent, to understand quickly and to think in these other languages, the result was certainly a failure.

What happens to the brain when multiple languages are learned? This is an interesting question. Is a separate neurone mechanism for each language set up in different speech areas of the cortex? My answer would be unequivocally "no."

Cases have been reported and published in which injury to the dominant hemisphere has resulted in the loss of one language and the preservation of another. If this claim were substantiated, one would be forced to assume that one area of cortex was used for French and another for Spanish. It is my opinion that careful study of these cases of aphasia would always show involvement of all the languages that have been mastered.

For twenty-five years I have lived and worked in a bilingual society in the Province of Quebec. Many patients speak French and English, often quite fluently. More than once I have heard from an assistant, who was well versed in the published literature on this subject, that an aphasic patient could speak French but was aphasic in English or vice versa. On critical examination it always developed that both languages were involved in the speech defect.

It is characteristic of certain types of aphasia that some words are lost and others retained. Sometimes one or more words are used over and over again. This may be done even when they fail to convey the speaker's meaning. A man may say "yes" when he wants to say "yes" but he continues, to his great chagrin, to say "yes" when he wants to say "no." He has lost the ability to say "no" and he can do no better in French, for he can say neither "oui" nor "non."

When more than one language is learned, the speech areas of the dominant hemisphere take them all on without geographical

separation that one can discover. If languages are learned in the right way, and particularly if they are learned at the right age, multiple languages may be learned perfectly, with little effort and without physiological confusion.

It has been said that an educated Englishman or American need not bother with other tongues. From the usual practical point of view this is no doubt quite true. The little-educated man and the university graduate get along, each with his mother tongue alone, quite well enough under ordinary circumstances. They may have no urge to travel for pleasure, profit or interest. They may not care to read current publications in other languages.

But there are many also who feel the urge to travel and read and who are not prepared for it by the schooling of the present day. There are many who believe that the goal of our present endeavor should be "One World," as Wendell Willkie phrased it. Many believe, as I do, that it is above all the bar of ignorance of language that shuts us off from other peoples, raising as it does a wall about our knowledge and understanding and brotherhood, far more impenetrable than distance or iron curtains.

It has long been one of the avowed objects of education to learn from other cultures. It has been agreed that this could best be done by speaking and reading the language of those other cultures. Hence the standard school exercises in Latin and Greek and in modern language. The problem is a very old one and it was not always solved in the same way.

I spoke of the discovery of writing in Sumer 5000 years and more ago. Semitic conquerors soon came into Sumer speaking a language which we may call Babylonian. They were warlike and untutored. They had much to learn from the more ancient civilization of Sumer. The temple libraries of that land and in that period were filled with clay tablets written in the Sumerian tongue.

Gradually, the common language in city and country came to be Babylonian, but contracts, decisions at law and bills of sale were still invariably written in Sumerian. Educated people understood both tongues.

Thousands of years later, Rome sent out her legions and conquered the world, but Romans had much to learn from Greek culture and their educated people came to know both tongues.

Barbarians in the north of Europe, among them the ancestors of some of us, threw off the domination of Rome. But, through the dark ages that followed, a scattered few, chiefly in the monasteries and castles, kept the Roman language alive and through it ran a slender stream of knowledge from the past until, at last, the day of the Renaissance dawned. Then Roman law, Greek thought and Hebrew religion burst into a new growth and the way was prepared for the birth of something quite new, Modern Science.

Today there linger echoes of this duality of tongue throughout all Christendom, for Latin is still current in the Catholic Church however little it may be understood, and even the relatively illiterate medical man speaks a certain sort of Latin in his anatomy lesson. He also writes Latin in his prescriptions and there, curiously enough, he never fails to bow the knee to an even more ancient culture – for each prescription is prefaced by a sign which resembles an R. It is the sign of Horus and it represents a prayer to that ancient Egyptian god of health that he will remove all evil from the drugs prescribed.

But times have changed and with them the learning of secondary language. The Babylonian once bought a Sumerian slave to teach his children, at an early age, a tongue that would be useful to them when they grew up to become priests, merchants, courtiers. Two thousand years later Roman families of the better class had Greek slaves and much respected Greek tutors.

In more recent times, governesses and maids who spoke foreign tongues could be hired, and this may well be possible in some parts of the world still. But slavery is gone and domestic servants seem to be fast disappearing on this continent.

The time has come to establish new methods of learning the secondary languages. Ignorance of foreign tongues cuts us off from the rest of the world and from the culture of other lands, which is just as important now as it ever was. To make up for this, foreign languages are taught in the final years of school and college. This is good but the effort yields a surprisingly small return.

I know quite well that educators are not in the habit of asking for physiological consultation in the planning of their curricula, and that the neurosurgeon who offers advice, unasked, may well be placing his head in the lion's mouth. This metaphor is par-

ticularly suitable since I am speaking in this venerable Academy of Arts and Sciences, and in Boston where almost everyone is an educator in one field or another.

It may be that the good Lord intended the educated man to read foreign languages painfully and by the sweat of his brow, as a sort of penance, regardless of how easily he learned to manage the mother tongue.

But one who considers only the physiology of the human brain might suggest that a few schools, at least, should be organized somewhat as follows:

Suppose the school which we are to discuss is a day-school in an English-speaking community. Let the first years, from nursery school and kindergarten on to grades for children of eight or ten, be conducted by foreign-born teachers who will speak only their native tongue in school, at work and at organized play.

If such a school is staffed, for example, by German and French teachers, and I make no plea for any particular language, let the little ones begin their years of normal play, drawing, singing and memorizing, in French or German. Teach them no language as such except by the methods so long employed by mother and nursemaid. After, possibly, two years in the French department, let them shift to the German department or vice versa.

Get on from fairy tales to folk literature as rapidly as the child's mind is prepared for it. These children will have been hearing Mother Goose and such things at home, and their play at the week-ends, as well as the home discipline, will have been carried out in English. In their holidays they will, no doubt, speak English.

Then, at the age of eight to ten, let the children take up mathematics, history and all the other subjects that should be mastered, including the dead languages as desired. This later stage may well be conducted in English with occasional exercises in French or German literature and conversation. They will then be able to pronounce their words and to concern themselves with the content of what they read.

During the first stage of education they will be learning to talk and to read and write. If this stage is properly handled the child will come through it with no more effort than when he learns one language instead of two or three.

Surely there are many parents who desire secondary languages for their children now, as in the past. Surely they would support such an undertaking, and the head-master who embarks on such a scheme, utilizing at the same time all that is best in modern pedagogy, will be besieged with applications from far and wide.

I make no pretence to knowledge of the best organization of such a school. My plea is that we should let children hear secondary languages, properly spoken, at an early age. On this continent we are shut off from easy contact with the rest of the world, and it is necessary to give some thought as to how we may make ourselves good citizens of the world as well as good Americans, good Canadians, good Englishmen.

I realize that there may be exceptional men, capable of learning language quickly at any age. There are always exceptions. It may be that such men, learning a language late in life, can speak without accent, although I doubt it. Joseph Conrad, born in Poland, spoke French as a secondary language from infancy. He came to live in England at 20, and became an English author who has thrilled us with his stories of the sea, written in English.

There is a good deal of evidence that he who learns more than one language as a little child has greater facility for the acquisition of additional languages in adult life.

The objection has been made that if a person learns a secondary language quite early, it may be completely forgotten with lack of practice. But let such a person live for a few weeks in the country where that language is spoken and he will discover that his former ability has not been lost nor the skill of pronunciation either.

The duration of man's childhood is very long as compared with that of other animals and the early years are normally devoted to learning a language as a means of learning about life. The human brain has a plasticity at that time and a specialized capacity for acquiring speech which is lost later. Perhaps we who glory in the power of adult reason and who have responsibility for teaching the young, might give some thought to the unalterable evolution of functional specialization in this brain of ours.

When we consider its complexity, composed as it is of thousands of millions of living nerve cells, each sending out or passing on individual electrical currents over insulated wire-like branches, it

does seem an unbelievable, a fabulous structure. It can even be used, as now, for self-contemplation.

The brain of man is the organ of destiny. It holds within its humming mechanisms secrets that will determine the future of the human race. Speech might be called the human brain's first miracle. Speech it was that served to make man what he is, instead of one of the animals.

The brain is a living mechanism, not a machine. In case of breakdown, it can substitute one of its parts for the function of another. But it has its limitations. It is subject to inexorable change with the passage of time.

We might well muse with the Psalmist:

"The days of our years are threescore years and ten; and if by reason of strength they be fourscore years, yet is their strength labour and sorrow; for it is soon cut off, and we fly away." Add, if you choose, another decade or two.

But remember that the brain passes through unalterable transitions. It is especially adapted to the learning of language at one stage and to the use of language in reasoned thought at another, a later stage.

"To everything there is a season and a time to every purpose under heaven." Educators, before all others, must realize that this is particularly true of the "organ of the mind." Physiological evolution causes it to specialize in the learning of language before the ages of 10 to 14. After that gradually, inevitably, it seems to become rigid, slow, less receptive. In regard to this function, it is soon senescent. But it is ready for life's fulfillment in other directions, ready for reasoning, self-discipline, understanding, even wisdom.

References

PENFIELD, W. and RASMUSSEN, T. 1949. *Vocalization and arrest of speech.* Arch. Neurol. & Psychiat., 61: 21-27.

PENFIELD, R. and RASMUSSEN, T. 1950. *The Cerebral Cortex of Man.* New York, Macmillan, 248 pp.

ROBB, J. P. 1948. *Effect of cortical excision and stimulation of the frontal lobe on speech.* A. Research Nerv. & Ment. Dis., Proc. (1947), 27: 587-609.

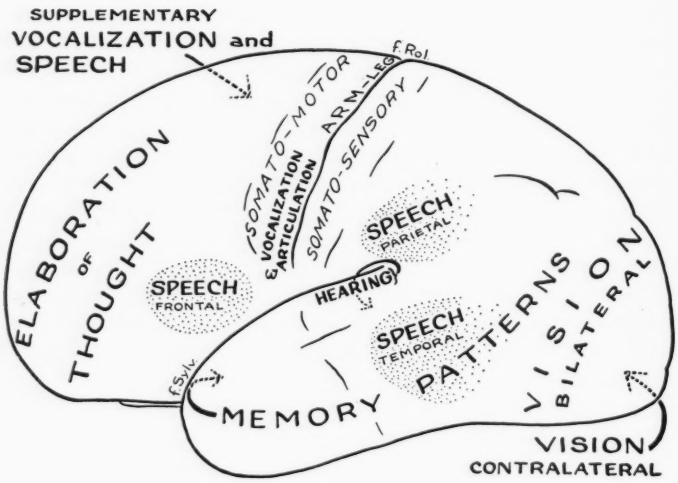
SUPPLEMENTARY
VOCALIZATION and
SPEECH
ELABORATION
OF
THOUGHT
SOMATO-MOTOR
VOCALIZATION
& ARTICULATION
ARM-LEG
SOMATO-SENSORY
SPEECH
PARIETAL
SPEECH
FRONTAL
HEARING
SPEECH
TEMPORAL
MEMORY
PATTERNS
VISION
BILATERAL
VISION
CONTRALATERAL

FIGURE 1